OCEAN REVERBERATION

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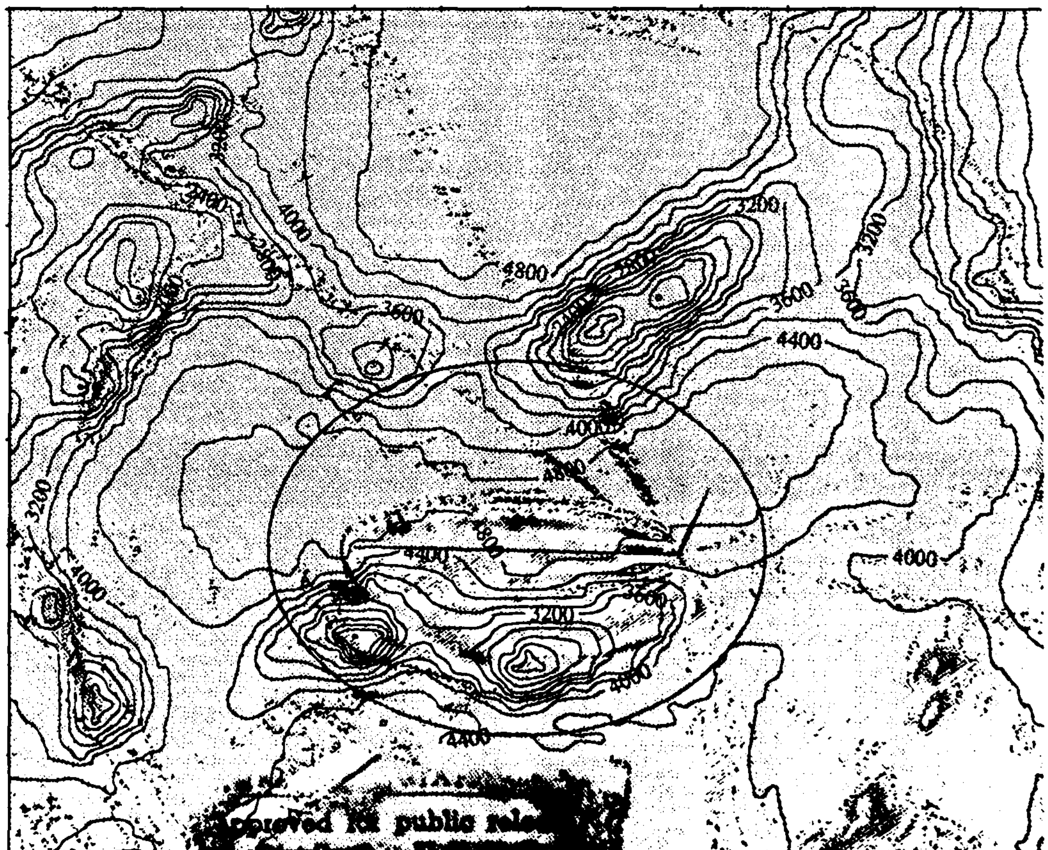

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Many measurements of volume reverberation have been conducted in the open oceans of the world. In May 1988, the Naval Research Laboratory at Stennis Space Center (NRL-SSC) had the opportunity to investigate volume reverberation in a unique region: the marginal ice zone (MIZ) of the Fram Strait between Spitsbergen and Greenland. Measurements were made from a drifting ice camp at three locations over a four day period. Volume scattering strength versus depth profiles were obtained at frequencies from 3.5 to 50 kHz using short CW pulses from a suite of downward and upward looking transducers. Results show that scattering layers occurred from about 100 to 200 m and 400 to 500 m at each location, with some variability in strength at the different locations. A comparison with volume scattering strengths reported from other cold water regions shows that values observed in the Fram Strait MIZ were lower than those reported at similar frequencies from open waters of the Norwegian Sea, Labrador Sea, and northern Baffin Bay, and comparable to those in the Denmark Strait, Davis Strait, Chukchi Sea MIZ, and northeast of Iceland.

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from Russian/Norwegian surveys in March-April of 1991 that recorded 5,200,000 tons of blue whiting, 28% of which were age 2 or less [2]. This indicates that the Faeroese survey recorded little of the adult stock.

Figure 6 compares measured column strengths with model results [3]. The modeling used fish depths based on observed layer depths and varied the number of fish to fit measured Sl's. Figure 6a shows the results obtained for Sites 6 and 7: using the Faeroese August blue whiting length distribution gives a good match, indicating that juvenile blue whiting were predominant at these stations. Figure 6b shows the results from Site 2: a blue whiting length distribution that is intermediate to those obtained by the Faroese in August and the Russians and Norwegians in the spring would give the best fit, indicating a mixture of juveniles and adults at this station. At Site 4, the spring blue whiting distribution was used to model the shallow layer and, since redfish are found between 300 and 500 m at these latitudes in the Norwegian Sea, a redfish length distribution from a Norwegian survey in the eastern Norwegian Sea in October 1991 was used to model the deep layer [4]. The model results for each layer agree with the data reasonably well, indicating that redfish and adult blue whiting are responsible for the deep and shallow layers respectively. However, the model peaks are a little closer together and broader in frequency than the data so that, when the layers are combined, as in Figure 6c, only one peak is apparent in the total modeled layer strength, compared to two in the data.

5. CONCLUSIONS

These measurements show that volume scattering strengths can be quite high in the Norwegian Sea in the summer. Layer scattering strengths in excess of -45 dB were measured at frequencies from 1 kHz to 5 kHz, with peak layer strengths as high as -38 dB occurring between 1.5 and 2.5 kHz. Layer strengths were lowest at the northernmost site. Comparisons to fisheries data suggest that the primary scatterers were blue whiting, which were more numerous and smaller to the south than the north, with concentrations of redfish in some areas.

6. ACKNOWLEDGEMENTS

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VOLUME REVERBERATION IN THE MARGINAL ICE ZONE OF FRAM STRAIT

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ABSTRACT Many measurements of volume reverberation have been conducted in the open oceans of the world. In May 1988, the Naval Research Laboratory at Stennis Space Center (NRL-SSC) had the opportunity to investigate volume reverberation in a unique region: the marginal ice zone (MIZ) of the Fram Strait between Spitsbergen and Greenland. Measurements were made from a drifting ice camp at three locations over a four day period. Volume scattering strength versus depth profiles were obtained at frequencies from 3.5 to 50 kHz using short CW pulses from a suite of downward and upward looking transducers. Results show that scattering layers occurred from about 100 to 200 m and 400 to 500 m at each location, with some variability in strength at the different locations. A comparison with volume scattering strengths reported from other cold water regions shows that values observed in the Fram Strait MIZ were lower than those reported at similar frequencies from open waters of the Norwegian Sea, Labrador Sea, and northern Baffin Bay, and comparable to those in the Denmark Strait, Davis Strait, Chukchi Sea MIZ, and northeast of Iceland.

1.INTRODUCTION

Volume reverberation measurements were made in May 1988 from an ice floe in the marginal ice zone (MIZ) of the Fram Strait by a team of scientists from the Naval Research Laboratory at Stennis Space Center (NRL-SSC). The experiment was located around 79°N and 0° to 3°W in the area where the West Spitzbergen Current meets the East Greenland Current, between Spitzbergen and Greenland. Volume scattering strength versus depth profiles were obtained at frequencies from 3.5 to 50 kHz using short CW pulses. Data were collected from May 15th to May 18th while the ice camp drifted westward about 80 km.

The Fram Strait MIZ is a unique region for several reasons. It is the only deep water channel between the Arctic Ocean and warmer waters to the south. The depth of the bottom in the Bering Strait is about 50 m, paths through the Barents sea must pass through areas around 300 m deep, and the Nares Strait between Baffin Bay and the Lincoln Sea is about 500 m deep. The Fram Strait, however has depths of 2500 to 3000 m. Strong currents bring polar water in from the north and North Atlantic water in from the south, as shown in Figure 1.[1] Eddies are common where these water masses meet and mix. There is a nearly permanent local gyre around the Molloy Deep near the experimental area. Temperature and sound speed profiles in the area have a large layer of low values near the surface, an abrupt increase around 100 m and smaller increases and decreases below this thermocline. Compared to other marginal ice zones, the ice edge in the Fram Strait does not change its position very much with the seasons. Ice is constantly drifting down from the north and melting as it reaches the polar front.[2]

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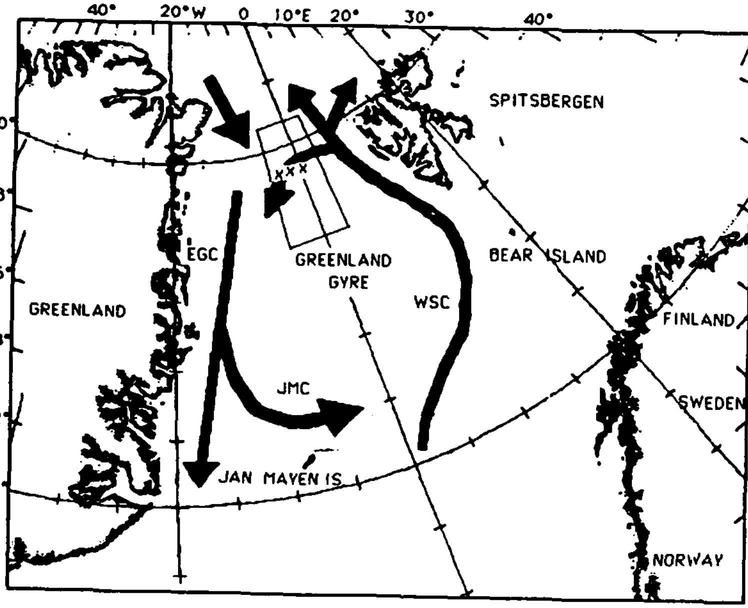

Figure 1. Locations of experimental stations shown in relationship to the prevailing currents in the area. EGC is East Greenland Current, JMC is Jan Mayen Current, WSC is West Spitsbergen Current.

2.THEORY AND METHODS

2.1 Biological Data:

At the lower end of our frequency range volume scattering in the ocean is caused primarily by gas-filled swimbladders of pelagic fish. At very high frequencies, however, the shells of planktonic animals become important sources of reverberation. Little information is available on fish in the Fram Strait, but sightings of seals, polar bear and walrus during the experiment indicated that under the ice there was a food source that was most likely fish. Two similar fish species, *Boreogadus saida* and *Arctogadus glacialis*, commonly called polar cod, are the main food sources for seals and polar bears. These fish have been found as far north as 84°N. One year old polar cod off the Labrador coast are about 9 cm long, but those from the arctic do not grow as fast.[3] Northeast Arctic cod, caught to the west and south of Spitzbergen north of Bear Island, consume young polar cod, redfish, capelin, and deep sea shrimp, 5 to 9 cm in length, and herring and haddock, 10 to 14 cm long.[4] Capelin, herring, and haddock are not found as far north as the MIZ 88 experiment site. Most adult redfish migrate into the Barents Sea in the spring and summer, but many larval and young redfish may be carried as far as the Fram Strait in the West Spitsbergen Current. Polar cod inhabit all parts of the Arctic Ocean and are known to spawn between December and February off Spitzbergen and in the southeast Barents Sea. Although they prefer cold water, polar cod may be at any depth seeking out the available food.[5] They have been caught in the Fram Strait, Svalbard area, and western Barents Sea.[6] Therefore, since they are known to be found in the experimental area and they have swimbladders, polar cod are potential sources of volume scattering.

Plankton surveys in the Fram Strait indicate that the most common zooplankton are the copepods *Calanus hyperboreus*, *Calanus finmarchicus*, and *Calanus glacialis*.[2] Also, polar cod caught near the under ice surface in the Fram Strait had mainly calanoid copepods, and amphipods in their stomachs.[7] Large numbers of copepods can be strong scatterers, as can aggregations of diatoms, ciliates and flagellates which are the main food sources for *Calanus*,[8] but only at much higher frequencies than were used in the MIZ 88 experiment. Small pteropods which are common in the Chukchi Sea MIZ possibly could be resonant scatterers at 30 to 50 kHz in the Fram Strait MIZ as well.[9]

2.2 Acoustic Measurements and Model:

The sources for this experiment were a set of 5 transducers generating 10 or 40 ms pulses at frequencies between 3.5 and 50 kHz. They were placed in the water just below the ice for downward looking measurements and at 65 m for looking up. For downward looking data, the first layer starts at 35 m, after the surface returns diminish. Upward looking data were obtained only at Station 2 from 3.5 to 12 kHz. Scattered signals were received by the same transducer, log amplified and analog recorded for further processing at NRL-SSC. About 10 pulses were averaged for each frequency and pulse length. Volume scattering strength, as a function of depth, was obtained using the following equation:

$$Sv = 20 \log V - SL - FFVS - 10 \log m - 10 \log(1-\cos(b/2)) + 20 \log t + act - Gain + 20.8$$

where Sv is volume scattering strength, V is voltage level of the received signal, SL is source level, FFVS is free field voltage sensitivity of the transducer, m is pulse length, b is the -3dB beam width, t is time, a is the attenuation coefficient, and c is sound speed.[10] Peaks in these profiles indicate the depths at which scatterers are most numerous. Integrating the scattering strength over a selected depth range gives a layer strength or column strength. Column strengths were calculated from the depth at which volume scattering data began to the bottom of the deepest scattering layer in the upper 800 m.

A swimbladder scattering model was employed to estimate sizes of fish responsible for observed scattering.[11] The length of a fish that would produce its maximum scattering strength at a given frequency and depth was estimated using the equation:

$$L = q[(z+10)/10]^{1/2} / \pi f$$

where L is the fish length, q is the ratio of the fish length to the effective radius of the swimbladder, z is the depth in meters, and f is the frequency in kHz. Selecting the right q value requires some knowledge of the type of fish that are found in the experiment area. A thin fish would have a larger q value than a fat one. For polar cod the q value is about 25.

3. RESULTS AND DISCUSSION

Figure 2 shows the Station 2 sound speed profile next to a scattering strength vs. depth profile. The upper scattering layer is above the thermocline in cold polar water brought

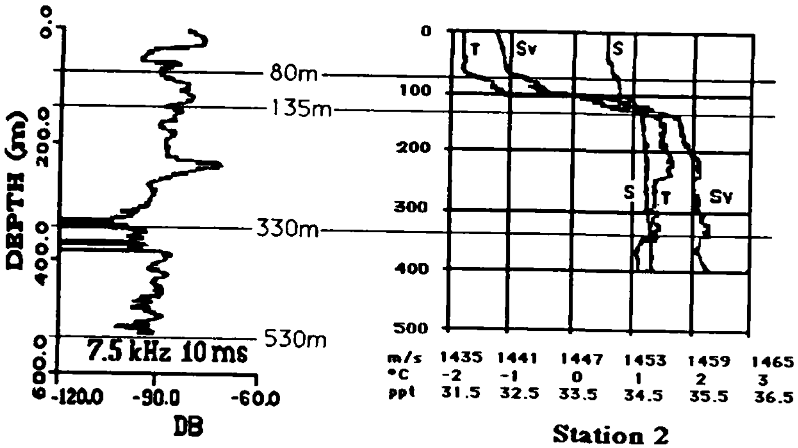

Figure 2. Layer boundaries chosen to coincide with temperature structure at Station 2

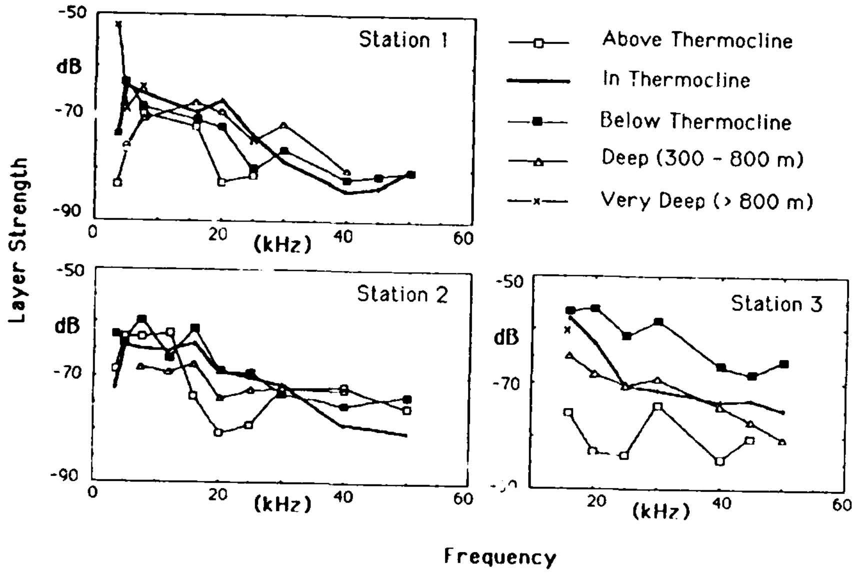

Figure 3. Layer strength vs. frequency for layers related to temperature profile.

from the north in the East Greenland Current. The second layer is in the thermocline where polar water is mixing with warmer Atlantic Intermediate Water and the temperature increases from -1.6° to +1.5°. The next layer is below the thermocline to 330 m. At 7.5 kHz there is also a deep layer from 330 to 530 m. Layer boundaries differ only slightly with frequency and station. Layer strength versus frequency data are shown in Figure 3. Values above the thermocline are notably higher when upward looking data are included. Lower frequencies generally have higher layer strengths. For Station 1, at the three lowest frequencies, there are five layers: four similar to those at Station 2 and one strong layer deeper than 800 m. Station 3 had a very deep layer also, but only at 16 kHz, which was the lowest frequency measured at that location. Above the thermocline, layer strengths for Stations 1 and 2 peaked between 5 and 16 kHz. If this scattering is from polar cod, they are between 1 and 4 cm long. That would indicate mainly 3 to 6 month and perhaps one year old fish. Stations 2 and 3 also have a layer strength peak at 30 kHz. This may be scattering from pteropods or larval fish about 7 mm long with an effective scattering radius about 0.3 mm. Polar cod 5 to 6 cm long could provide scattering layers at the depths and low frequencies of the in thermocline and below thermocline layers of Stations 1 and 2. The 300 to 800 m layer peaked at 16 kHz for all three stations. This could be caused by polar cod 3 to 4 cm long, or perhaps young redfish or Atlantic cod.

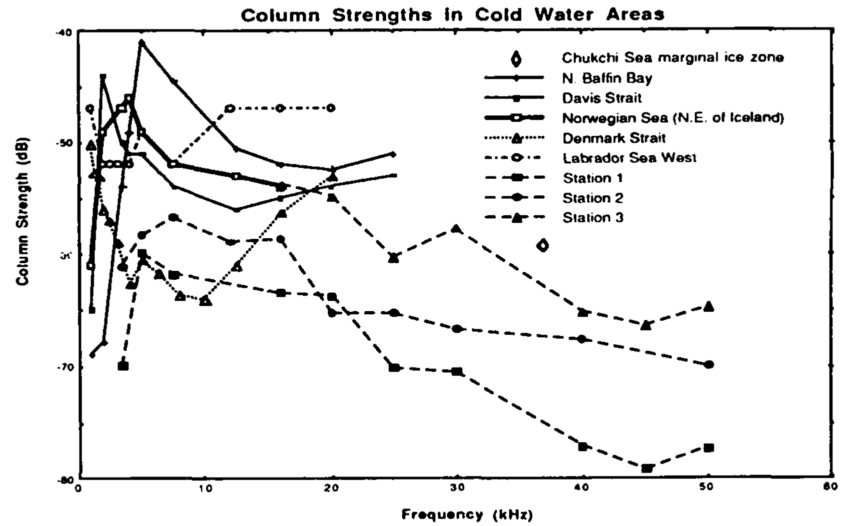

Figure 4. Column Strengths for the upper 800 m in the Fram Strait marginal ice zone and for other cold water areas.

Figure 4 shows column strengths for the Fram Strait and other cold water areas for comparison. Column strengths in the Fram Strait increased as the ice floe drifted west in the MIZ. Levels at Station 1 and 2 are similar to those in other cold water straits and lower than those in open water. Station 3 data matched some Norwegian Sea data from northeast of Iceland at 16 kHz, the only frequency at which they overlapped. Data from other parts of the Norwegian Sea were generally higher. The Chukchi Sea MIZ data at 38 kHz was about the same as Station 3 data at 30 kHz, but higher than that for 40 kHz.

4. CONCLUSIONS AND SUMMARY

Column strengths in the Fram Strait MIZ varied between -50 and -80 dB in the 3.5 to 50 kHz range with a general decrease from low to high frequencies. Levels increased as the ice camp moved toward the Greenland continental shelf. The variations of layer strength with frequency indicate more than one scattering species. Young polar cod from 2 to 6 cm long are the most likely scatterers in the lower part of the frequency range. The peak layer strengths at 30 kHz and above may be from larval fish or perhaps pteropods.

5. ACKNOWLEDGEMENTS

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Section 7

Signal Processing Issues